Low Hydrogen Embrittlement (LHE) Zinc-Nickel (Zn-Ni) Qualification Test Result and Process Parameters Development

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Report Documentation Page

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LHE Zn-Ni Background

- Boeing C-17 Program cadmium replacement research (2002-2006)
- Small Business Innovative Research (SBIR) Phase I Feasibility Study (2007-2008)
- SBIR Phase II Qualification Testing (2008-2010):

AFRL TIM 26 May 2011

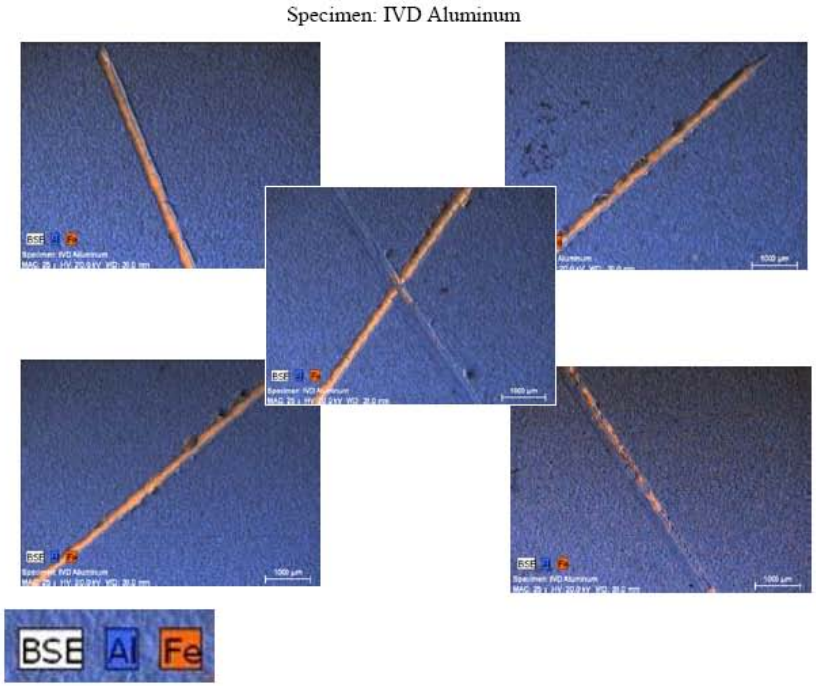
- A Technical Interchange Meeting (TIM) was conducted at ASC/EN on 26 May 2011 with participants from: OO-ALC/GH, ES3, AFRL/RX, Boeing, and ASC/EN Following AFRL concerns were discussed about the Zn-Ni Phase II test report:
  - Scribe Tests (Corrosion Tests)
  - Hydrogen 'Re-'Embrittlement Tests
  - Fatigue Tests
- These were the only items in which action items were opened

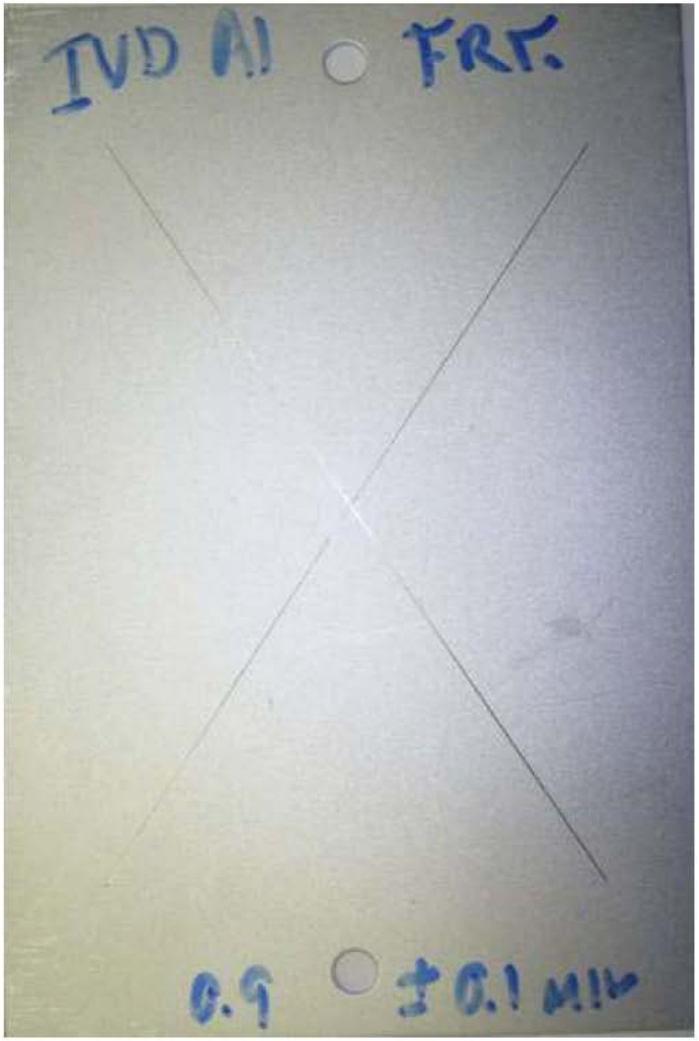
Corrosion (Scribe) Testing

- Scribe Test Action Item #1:
  - Provide 1000 hrs panel scribe data to AFRL for evaluation.
- Response:
  - Original 1000 hrs panels are not available - they were tested to 5000 hrs
  - Consequently, Boeing Research & Technology (BR&T) evaluated standard carbide scribe technique and the team determined that the process is repeatable and exposes a sufficient amount of base metal to provide valid test results
  - Also, BR&T determine that the original corrosion panels were machined scribed and not carbide scribed by hand (i.e. machined scribed the preferred AFRL scribing method)
  - BR&T hand scribed panels and ran SEM EDX scans to determine IF they could reach the bare metal substrate; see following slides

Corrosion (Scribe) Testing

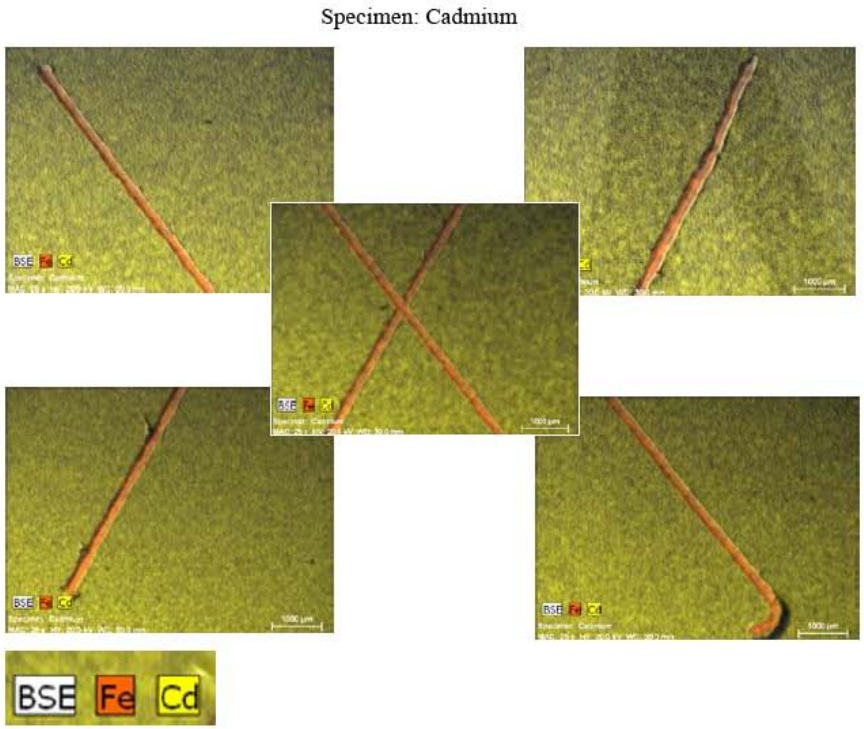
IVD Aluminum

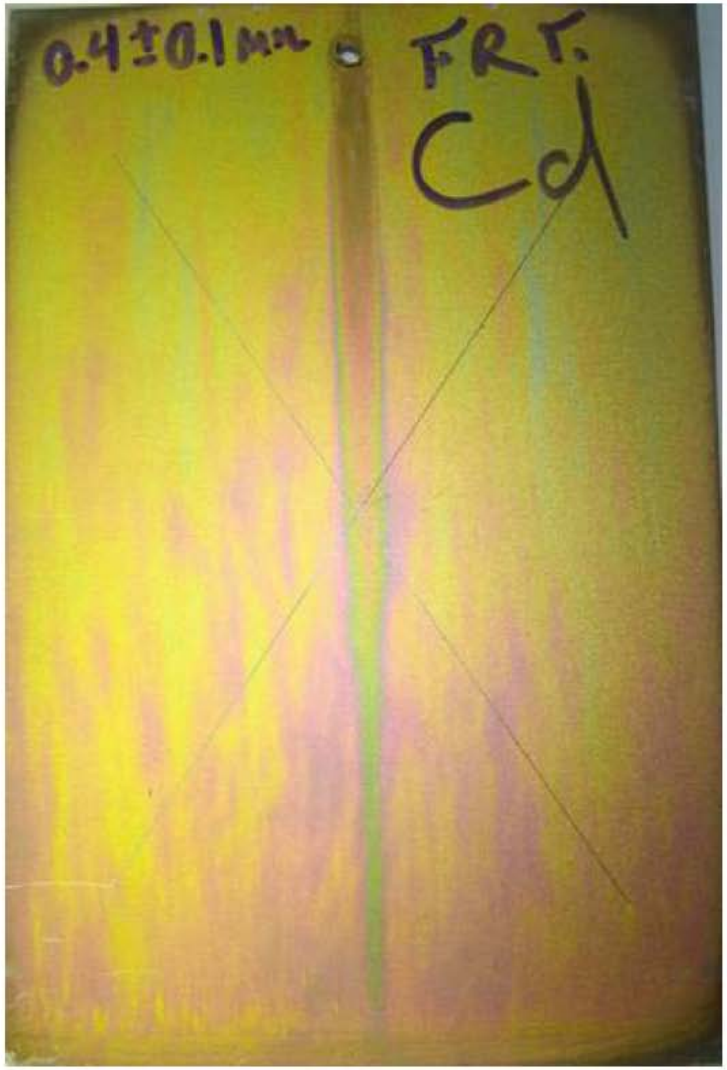




Corrosion (Scribe) Testing

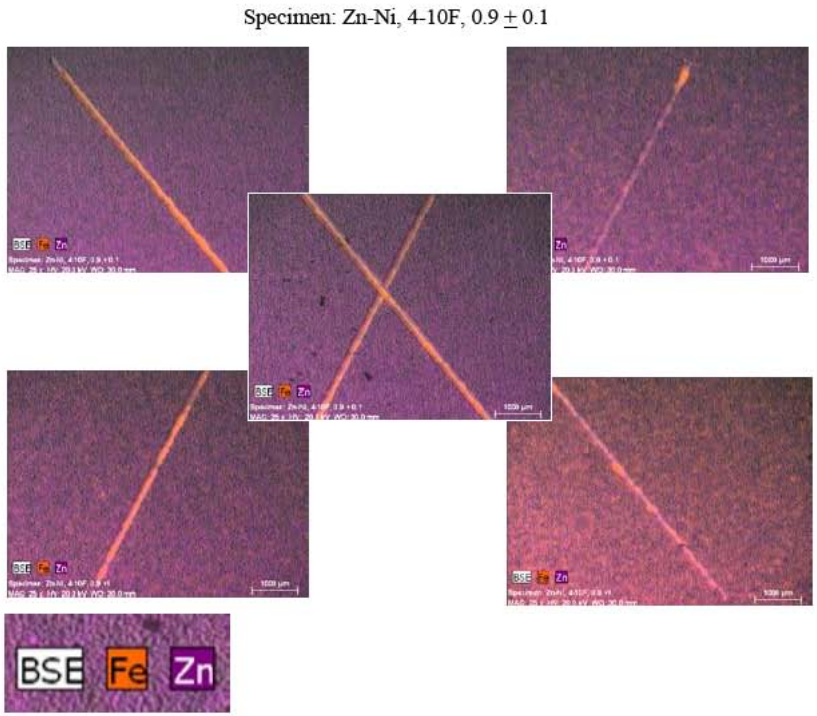
Cadmium





Corrosion (Scribe) Testing

Zn-Ni



Corrosion (Scribe) Testing

- Scribe Test Action Item #2:
  - Boeing to machine scribe Zn-Ni and Cd panels and test them for 1000 hours for a direct comparison
- Response:
  - Additional machined scribed Zn-Ni and Cd panels have been corrosion tested by BR&T per ASTM B 117
  - All the Zn-Ni plated panels passed the corrosion requirements called out in QQ-P-416 (no white corrosion products for 96 hours)
    - Results are shown in following slides below

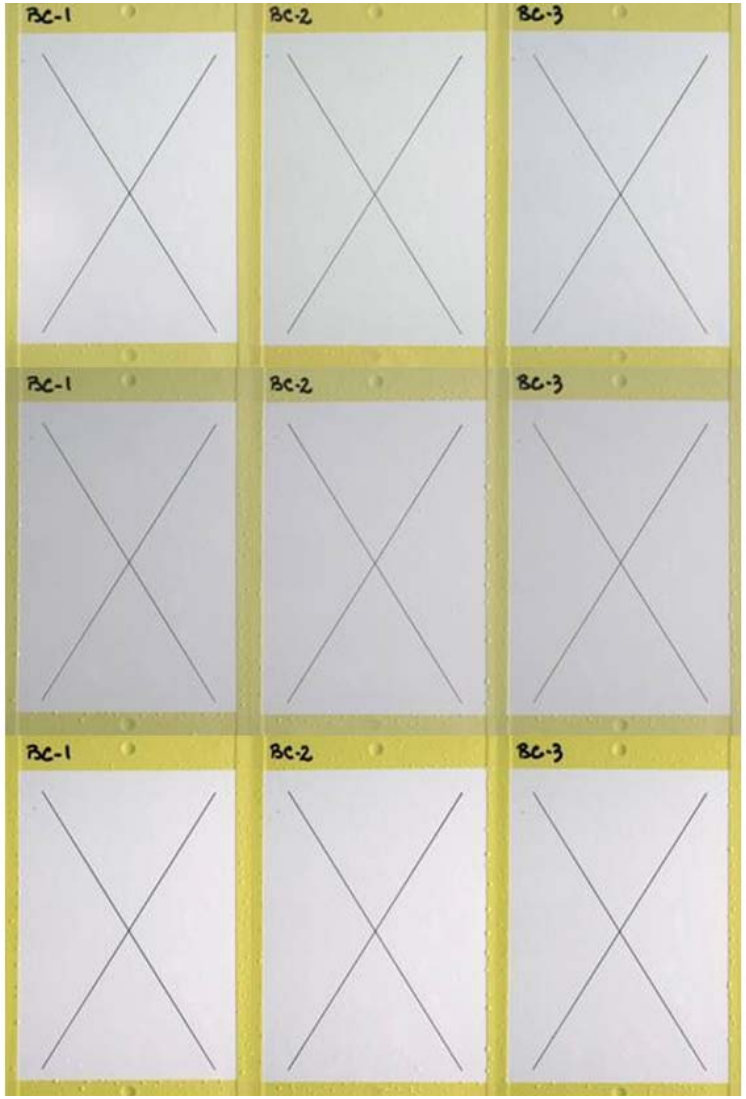
Corrosion Re-Testing

Table 1 - Machine vs. Carbide Scribed Corrosion Test								
Group No.	Test Specimen* Identification	Plating Material	Conversion Coat Type	Plating Thickness (mils)	Primer + Topcoat	Type of Scribe	Test Duration**	Test Results
1	BC1	Zn-Ni	TriCr	0.6 +/- 0.15	Yes	Machined Scribe	1000 hrs	PASS
	BC2	Zn-Ni	TriCr	0.7 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
	BC3	Zn-Ni	TriCr	0.7 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
2	HC1	Zn-Ni	TriCr	0.8 +/- 0.2	Yes	Machined Scribe	1000 hrs	PASS
	HC2	Zn-Ni	TriCr	0.8 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
	HC3	Zn-Ni	TriCr	0.8 +/- 0.2	Yes	Machined Scribe	1000 hrs	PASS
3	HC4	Cd	HexCr	0.8 +/- 0.05	Yes	Machined Scribe	1000 hrs	PASS
	HC5	Cd	HexCr	0.7 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
	HC6	Cd	HexCr	0.5 +/- 0.1	Yes	Machined Scribe	1000 hrs	PASS
4	BS1	Zn-Ni	TriCr	0.8 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
	BS2	Zn-Ni	TriCr	0.7 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
	BS3	Zn-Ni	TriCr	0.8 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
5	HS1	Zn-Ni	TriCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	PASS
	HS2	Zn-Ni	TriCr	0.8 +/- 0.05	No	Machined Scribe	1000 hrs	PASS
	HS3	Zn-Ni	TriCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	PASS
6	HS4	Cd	HexCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL
	HS5	Cd	HexCr	0.7 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL
	HS6	Cd	HexCr	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL
7	BS4	Zn-Ni	None	0.8 +/- 0.1	No	Machined Scribe	1000 hrs	FAIL ****
	BN1	Zn-Ni	None	0.7 +/- 0.1	No	No Scribe	1000 hrs	PASS ****

**** Group 7 test coupons were run without conversion coating and were not required to pass (i.e. information only)

BR&T ASTM B 117 Corrosion Test Results

BR&T IZ-C17+ Zn-Ni w/Tri CC Scribed & Painted

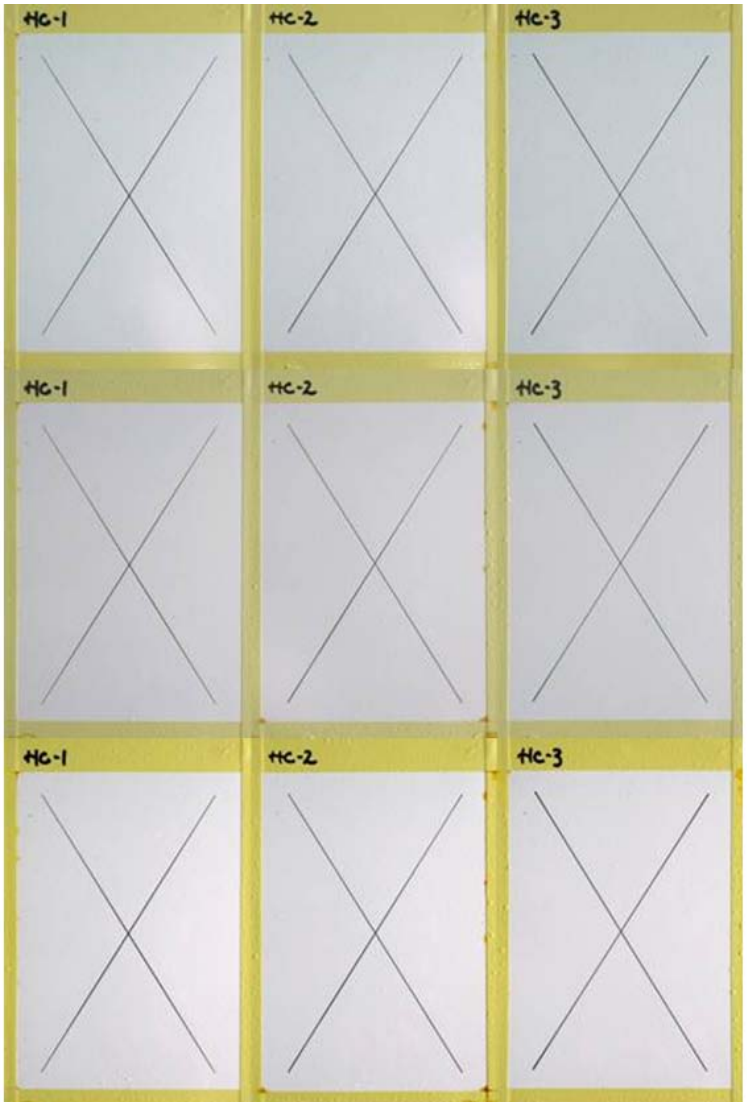


336 hours

672 hours

1000 hours

Hill AFB IZ-C17+ Zn-Ni w/Tri CC Scribed & Painted

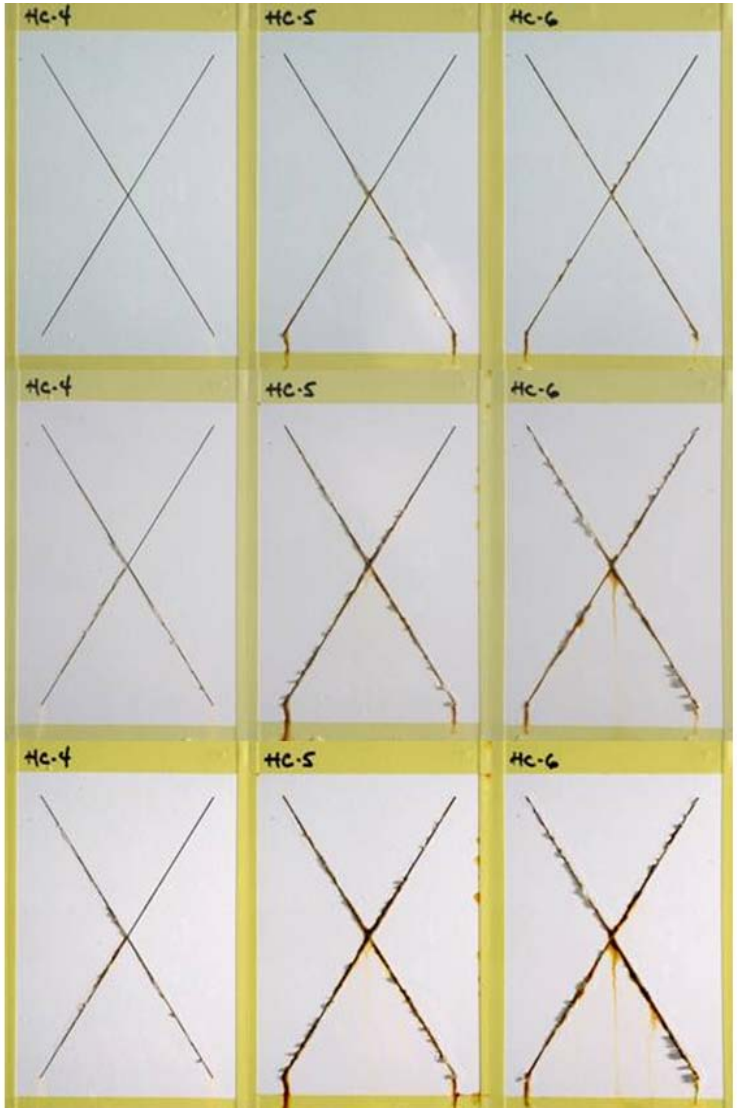


336 hours

672 hours

1000 hours

Hill AFB LHE Cd w/Hex CC Scribed & Painted

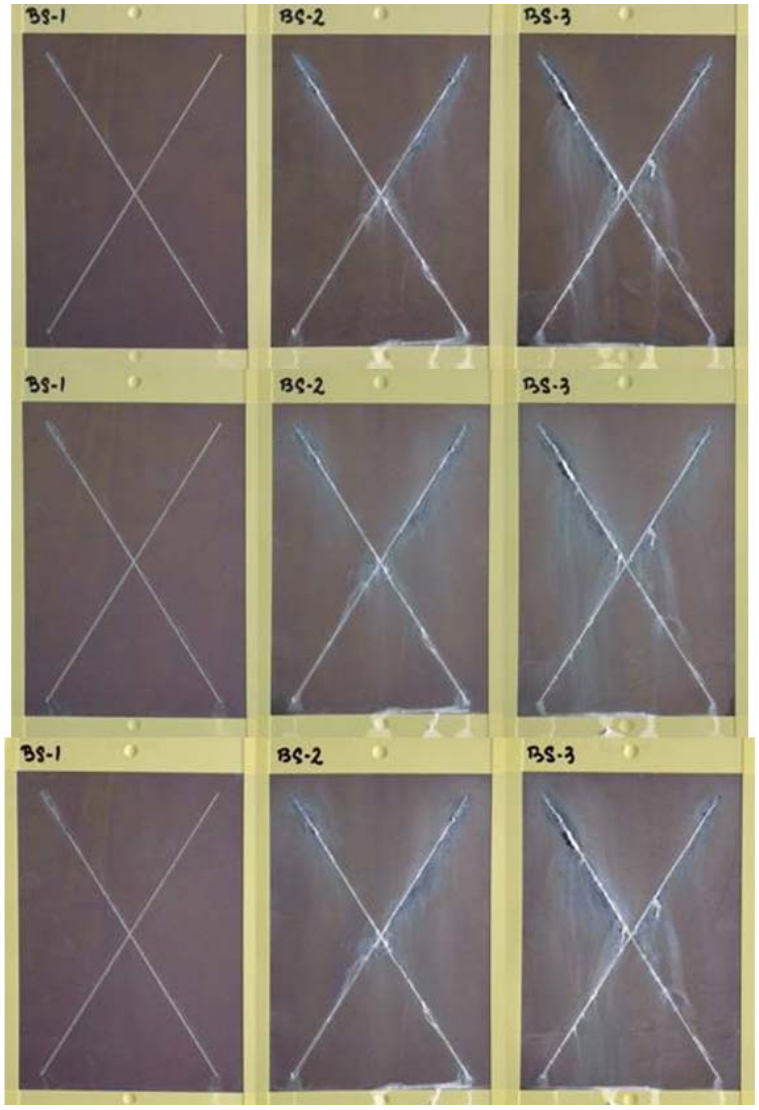


336 hours

672 hours

1000 hours

BR&T IZ-C17+ Zn-Ni w/Tri CC Scribed

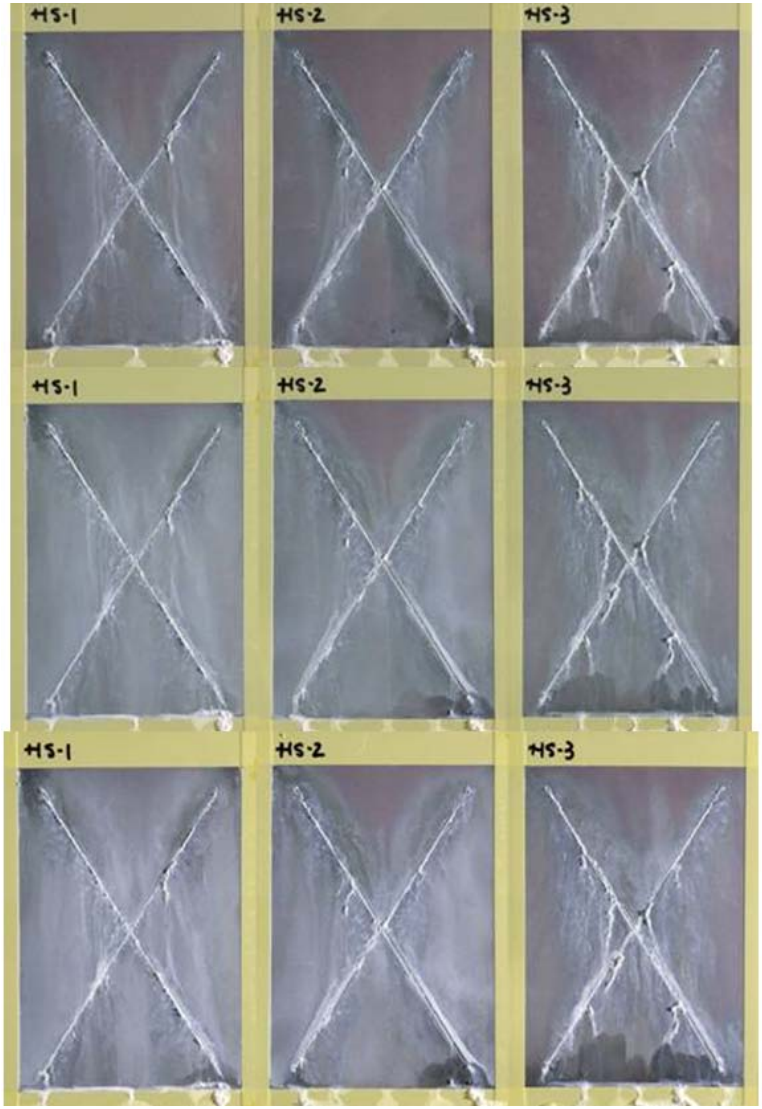


336 hours

672 hours

1000 hours

Hill AFB IZ-C17+ Zn-Ni w/Tri CC Scribed



336 hours

672 hours

1000 hours

Hill AFB LHE Cd w/Hex CC Scribed

336 hours

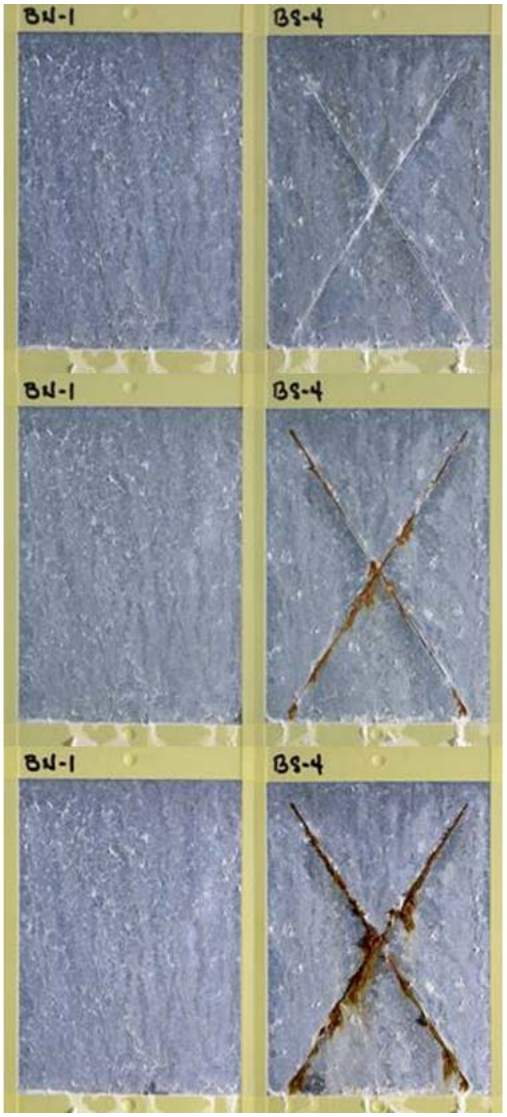
672 hours

1000 hours

BR&T IZ-C17+ Zn-Ni w/ No CC Unscribed & Scribed

Requirements for Chrome Reduction / Elimination; determine how the plating works without ‘any’ conv. coat.

Group 7 test coupons were run without conversion coating and were not required to pass (i.e. information only)



336 hours

672 hours

1000 hours

Hydrogen 'Re-'Embrittlement For Service Environments Testing

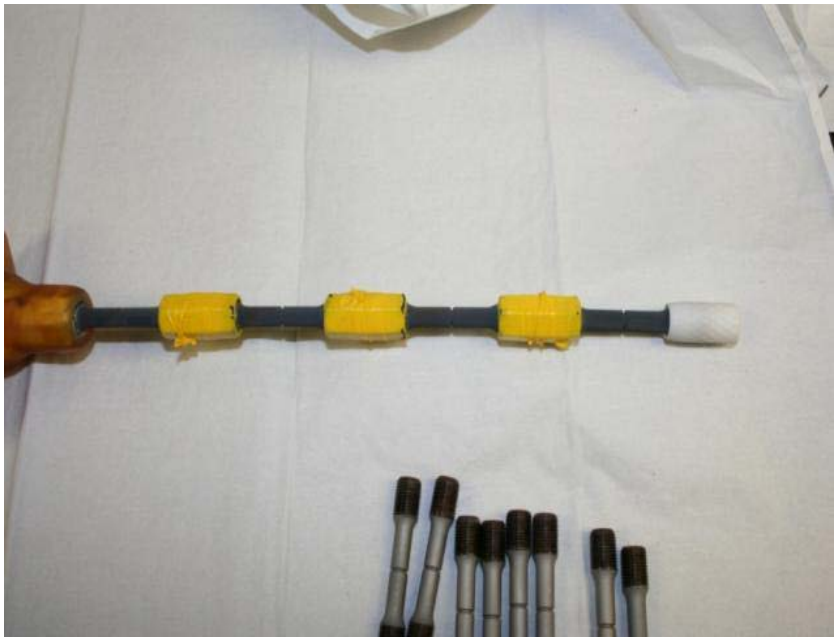
- 'Re-' Embrittlement Test Action Item #1:
  - Determine the reason for the poor plating on the original LHE Zn-Ni 1a.1 re-embrittlement coupons
- Response: See following slides

Hydrogen 'Re-'Embrittlement For Service Environments Testing

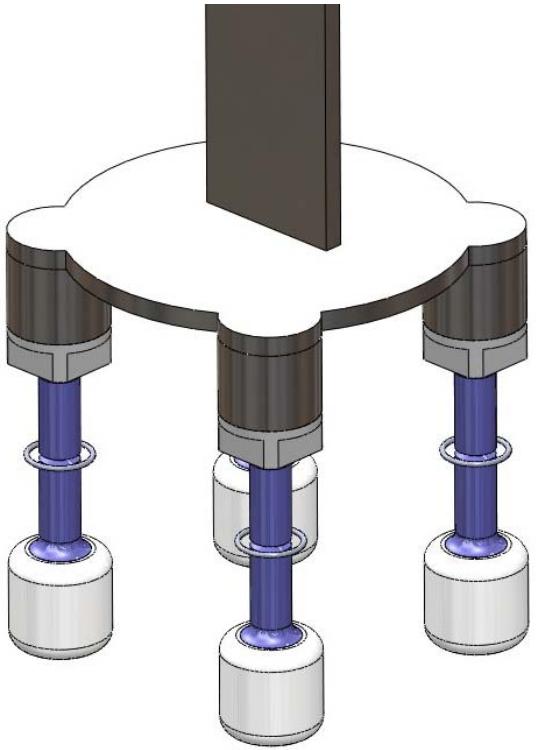
- The reason for the poor plating on the original LHE Zn-Ni 1a.1 re-embrittlement coupons are as follows:
  - Zn-Ni tank contamination
    - Spring '09 Lab analysis showed organic contamination
    - The PVC tank liner had begun to break down and had to be replaced in the Summer '09 with a more robust grade of PVC liner.
    - Two years operating with new liner with no problems
  - Inconsistent plating in notch area
    - Specimens were chained in series when they were plated for the first series of tests
    - Now a fixture and conformal anode is used to ensure that there is uniform plating throughout the notch area
    - Also circulation has been added around the notch area during plating

Hydrogen 'Re-'Embrittlement For Service Environments Testing

Original Coupons Chained in Series



New fixture and Conformal Anode



Hydrogen 'Re-'Embrittlement For Service Environments Testing

- Additional, 3.5% salt water, re-embrittlement testing has been conducted on LHE Zn-Ni plated coupons and they all passed the ASTM 519-06 150 hour requirement

Re Embrittlement Test Matrix						
Plating	Test Solution					
	Distilled Water @ Room Temp Tested 45% NFS for 150Hrs	3.5% Salt Water @ Room Temp Tested 45% NFS for 150Hrs	Dwg 9825019* Diluted Calla 296 @ Max Temp 180 °F Tested 75% NFS for 200Hrs	Dwg 9825019* Diluted Calla 602 LF Max Temp 160 °F Tested 75% NFS for 200Hrs	Concentrated Calla 296 @ Room Temp tested 45% NFS for 150Hrs	Concentrated Calla 602LF @ Room Temp tested 45% NFS for 150Hrs
LHE Zn-Ni	Passed	Passed	Passed	Passed	Passed	Passed
Cadmium	Passed	Failed	Passed	Passed	Passed	Passed
IVD	Failed	Failed	Not Tested	Not Tested	Not Tested	Not Tested

*The specimens were immersed in the cleaning compound at the manufacturer's maximum recommended temperature, and appropriate cleaning concentration, for 30 minutes. Removed. Air dried and loaded to 75% NFS for 200Hrs.

Hydrogen 'Re-'Embrittlement For Service Environments Testing

- 'Re-'Embrittlement Test Action Item #2:
  - If possible, repeat the Boeing voltage potential test on plating of the original LHE Zn-Ni 1a.1 re-embrittlement coupons and compare the voltage readings to current LHE Cd and LHE Zn-Ni plated coupons. Boeing indicated that it might not be possible due to the shape and amount of surface area on the 1a.1 re-embrittlement coupons. (if possible)
- Response:
  - An accurate corrosion potential test in salt water per ASTM G5 could not be conducted because of the following:
    - Geometry differences of the 1a.1 coupon vs. standard ASTM G5 corrosion potential test coupon
    - The 1a.1 coupons were contaminated by salt water exposure during initial re-embrittlement testing.

Hydrogen 'Re-'Embrittlement For Service Environments Testing

- 'Re-'Embrittlement Test Action Item #3:
  - Determine the quality thickness of the Cd, Zn-Ni and IVD evaluated in the salt water test.
- Response:
  - Quality and thickness of plating were unacceptable
  - See Action Item #1 addressed poor plating quality
  - Salt water testing was repeated

Hydrogen ‘Re-’Embrittlement For Service Environments Testing

- Conclusion: Poor plating cause identified and corrected
- Zn-Ni testing was repeated with production plating process and passed ASTM 519 hydrogen ‘re-’ embrittlement service environment test in 3.5% salt water

Fatigue Testing

- Fatigue Test Action Item #1:
  - Clearly document any test data that was discarded in the fatigue test plots and the supporting rational and provide it to OO-ALC/GH, AFRL/RX and ASC/EN
- Response:
  - All fatigue test data was included in the statistical analysis

Fatigue Testing

- Fatigue Test Action Item #2:
  - Provide information on the measured plating thickness on each specimen to OO-ALC/GH, AFRL/RX, and ASC/EN
- Response:
  - A conservative approach was taken when the Zn-Ni fatigue coupons were plated:
    - All Zn-Ni fatigue coupons were plated thicker than cadmium fatigue coupons (typical thickness 0.0002 - 0.0006 inches)
    - The nickel content for Dipsol Zn-Ni IZ-C17+ was closer to the upper limit (18%) of the USAF 201027456 plating specification drawing

Average Plating Thickness	(Inches)
Cadmium	0.00044
Dipsol Zn-Ni Tri CC	0.00091
Dipsol Zn-Ni Hex CC	0.00104
Atotech Zn-Ni Tri CC	0.00089
Atotect Zn-Ni Hex CC	0.00081

Fatigue Testing

- Fatigue Test Action Item #3:
  - OO-ALC/GH to engage the Landing Gear Design Industry and determine if the fatigue testing and test results per the following fatigue testing matrixes is adequate to approve the use of LHE Response:

- Goodrich Landing Gear, John Goering; when asked, "…considering the test method for comparative fatigue debit that we have conducted; would you say that you have complete, very high, high, medium or low confidence that this LHE Zn-Ni coating would not induce a greater fatigue debit than cadmium?" Response was high to very high.

Phase II Fatigue Testing

- Boeing Commercial (SDT) group evaluated the LHE Zn-Ni fatigue data and saw nothing that would alter their conclusion of the acceptability of the use of LHE Zn-Ni on high strength steel landing gear components
  - Boeing Commercial has approved LHE Zn-Ni for high strength steel and is currently installing a LHE plating line
  - Structural Design Team stated that only one stress ratio is necessary and testing at different R ratios will yield the same result.
- Dr. Andrew Halfpenny a fatigue expert, from HBN Inc., reviewed the fatigue data and determined that the LHE Zn-Ni is a suitable drop in replacement for cadmium

Phase II Fatigue Testing

- Heroux-Devtek stress group evaluated the LHE Zn-Ni fatigue data and concluded it is acceptable for use on high strength steel landing gear components
  - Heroux-Devtek has approved LHE Zn-Ni for high strength steel and is currently installing a LHE plating line
  - Stress group stated that only one stress ratio is necessary and testing at different R ratios will yield the same result
- Boeing-Long Beach, structures group, would like to see additional testing (with more R ratios)
  - ES3 conducted two different R rations during testing
  - Boeing-Long Beach did not indicate how many test, at what R ratio would be satisfactory to them

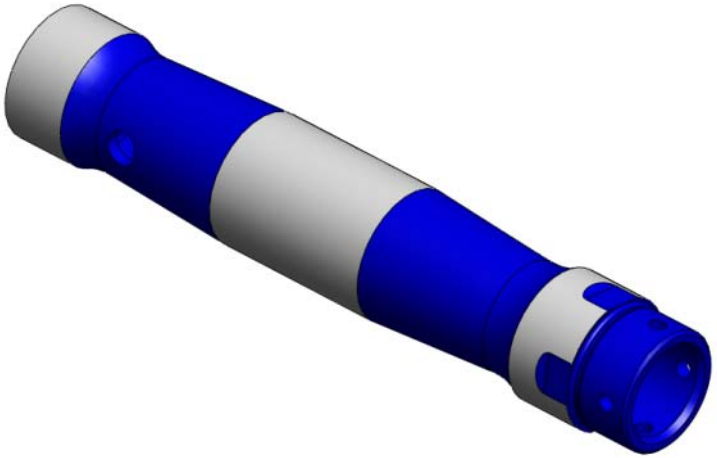
Planned Evaluation

- Prototype line in Bldg 505
- Field Performance Evaluations

Phase III Effort
Prototype Process Line

Part Matrix	
Component	Part #
C-5 MLG Stop Plate	4G11453-101B
F-15 MLG Outer Cylinder	68A412702-1001/1002
B-1 MLG Axle	1881B85
F-15 MLG Lower Drag Brace	68A410792-2001
A-10 MLG Torque Arm	19046-1
F-16 NLG Inner Cylinder	2007644-103
C-5 MLG Rotation Collar	4G13565-101A/-101B
A-10 NLG Axle	18800-3

Phase III Effort
Prototype Parts



A-10 NLG Axle

A-10 MLG Torque Arm

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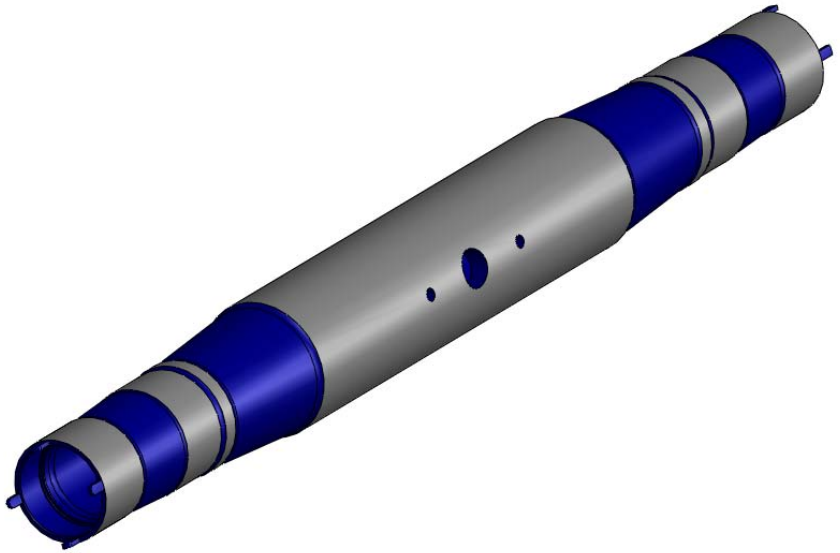
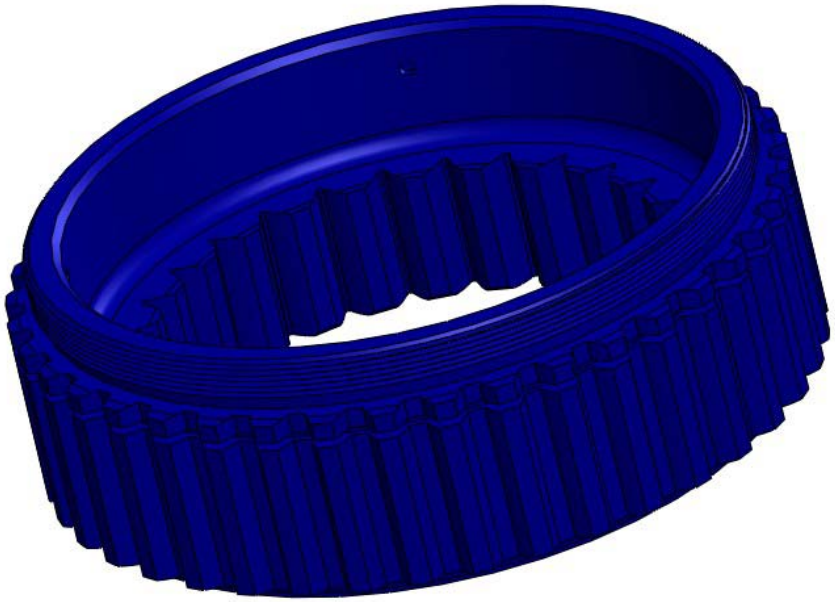
Phase III Effort
Prototype Parts



B-1B MLG Axle



C-5 MLG Rotation Collar

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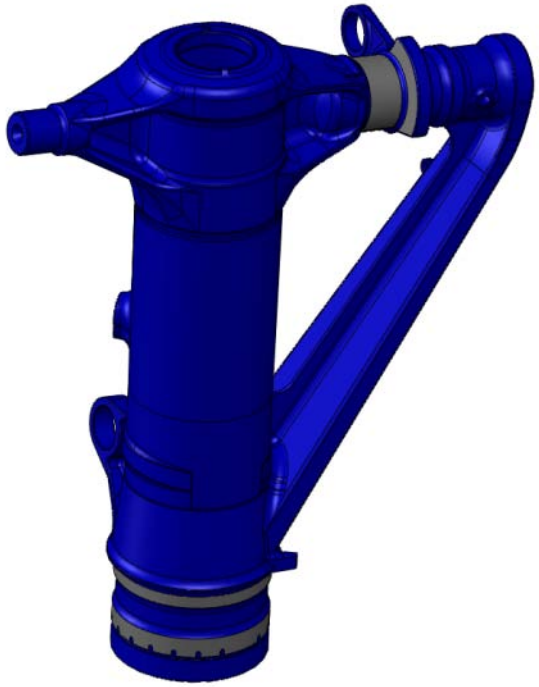
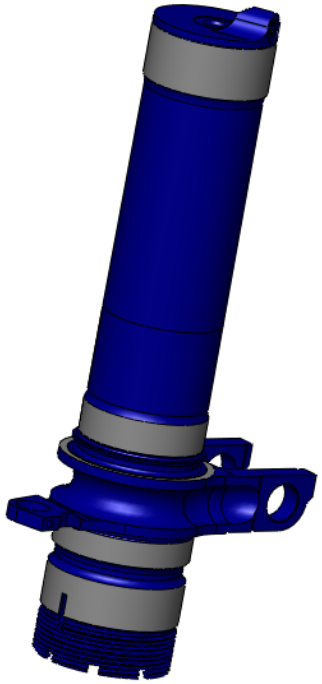
Phase III Effort
Prototype Parts



F-15 MLG Cylinder



F-16 NLG Inner Cylinder

F-15 MLG Lower Drag Brace

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Discussion/Questions

QUESTIONS